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ANALYSIS OF IMPACT CRATER ARRANGEMENT ON THE VENUTIAN SURFACE

(From photographic materials of the Venera - 15 and -16 Spacecraft)

V. P. Kryuchkov

Translation of " Analiz razmeshcheniya udarnykh Kraterov na Poverkhnosti venery", Seriya Geologicheskaya, No. 6, 1987, pp 75-83

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16. Abstract

This work discusses for the first time the population of impact structures on the entire surface areaon Venus encompassed by photographs made on Venera-15 and -16 space vehicles. Distribution of impact craters by classes and as a whole is presented. It is found that the average age of the observed impact craters is approximately 1 billion years.

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ANALYSIS OF IMPACT CRATER ARRANGEMENT ON THE VENUTIAN SURFACE

(from photographic materials of the Venera - 15 and -16 spacecraft)

V. P. Kryuchkov

Typical impact craters have been positively identified /75* on photographs of the Venutian surface obtained by side-scanning radar on the Venera - 15 and -16 space vehicles. Annular formations have previously been isolated on Venus: on radar images of the Pioneer - Venus spacecraft and in ground radar observations (for example [8, 11]). They were interpreted as impact craters with a lot of stipulations, however. This was due to the fact that they were defined based on a picture of the distribution of radio brightness and surface irregularity, as well as from individual altimetric measurements, and not from all the direct morphological details of the surface relief. Comparison of the images of these annular formations from the data of previous and the latest photographs demonstrated that only some of them were impact craters, while in the majority of cases they belonged to other types of annular structures.

Preliminary research of impact craters whose results were previously published [1-4] has only been conducted for part of the photographic territory of the Venera-15 and -16 space vehicles (as radar images came in). This work discusses for the first time the population of impact structures on the entire surface area encompassed by these photographs. All of the observed morphological components in the structure of these formations, annular depression, well-pronounced swell, central hill, light halo around depression and some other geologigcal signs are similar to the set of structural components of impact craters of the Moon and other planetary bodies. The light halos around the morphologically fresh Venutian craters could be ejecta from them or the results of interaction between the air shock wave and the surface [10]. They are most likely related to both. Annular formations have also

*Numbers in right margin indicate pagination in original text.

been found on Venus which morphologically differ noticeably from the morphology of impact craters. They include: volcanic calderas; ovoids, large structures from 150 to 600 km in diameter delimited by a system of narrow parallel, concentric ridges and furrows; structures of cobweb-like shape, formations with diameter from 70 to 250 km with a nucleus often in the shape of a cupola elevation surrounded by broad, gently sloping concentric swells (from 1 to 3) and narrow ridges radially diverging from it. It is hypothesized that all of these structures have endogenous origin [2,3]. In addition to these easily recognizable annular structures, the examined Venutian territory has widespread formations of rounded or somewhat elliptical shape, but with morphologically weakly pronounced depression and its swell-like surrounding region. The structural elements of these forms are either destroyed or covered by surface material making it difficult to trace even the complete contour of their external surrounding region. These slightly pronounced formations with easily identifiable annular structures have not been identified in morphological structure, and therefore they are classified as structures of unclear genesis. Of all these diversities in annular formations, this work will only discuss those /76 structures which can be classified as impact craters in their morphology.

The set of impact craters on the photographed area (115×10^6 km^2) consists of 147 structures. The critical diameters of these craters are: minimum 8 km, maximum 136 km. Under favorable interpretation conditions, for example, on level surface sections, sometimes craters are observed with diameter less than 8 km, but on more complexly constructed surface sections, these small craters are not visible, to all likelihood because of the insufficient resolution of the radar photographs (1 - 2 km) and the very rugged terrain. Structures less than 8 km were therefore not included in the statistical processing.

The entire set of impact craters is divided into four classes in sequence from the morphologically recent (I class) to the morphologically ancient (IV class) (fig. 1). The most recent

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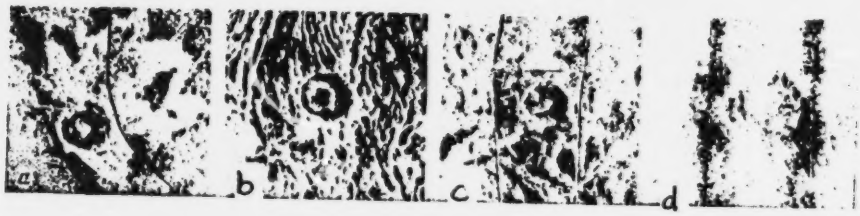

Figure 1. Radar Images of Impact Craters of Different Classes

Key:
a. I b. II c. III d. IV

craters of the I class (fig. 1,a) include structures which have preserved well the morphological signs of the impact: distinct round shape of the depression undestroyed by anything, the presence of a well-pronounced swell, distinct central hill in those structures where it exists, and easily seen light halo. The II class (fig. 1b) includes craters which lack a light halo, but the other morphological structural components listed for the I class are maintained, although in a slightly milder form. In craters of the III class (fig. 1,c) there is a noticeable degradation of the depression, the destroyed ridge ofthe swell is read with difficulty, and remains of the destroyed central hill are generally observed. Craters of the IV class (fig. 1,d) are defined from the presence of a still preserved round depression, interrupted outliers of a swell and sometimes residues of a central hill.

Distribution of impact craters depending on the diameter of both the entire complex and individual morphological classes is presented in table 1 and fig. 2. Attention is drawn to the explicit dominance of II class craters over the others. If I and II class craters are combined into the common category of recent craters, and III and IV craters into the category of old craters, then it turns out that the recent structures are more widespread than the old. The same distribution of impact craters is observed on the surface of lunar seas where the morphologically recent structures of similar diameters (8 - 130 km) dominate over the morphologically old, but the opposite correlation is characteristic for the continental surface of the Moon.

In order to define the time for formation of the observed population of impact craters, model diagrams of W. K. Hartmann were used that were especially calculated for Venus (with regard for the influence of the atmosphere on the passage of crater-forming bodies through it and without consideration for this influence) [7]. It was found that the density curve for distribution of impact craters of various diameters, being plotted on the diagram considering the influence of the atmosphere, intersects the model isochrones. As W. K. Hartmann indicates, the reason for this intersection could be the significant degradation in a considerable part of the population of impact craters [7]. However, the aforementioned dominance of the fresh impact craters in the observd population apparently excludes such an interpretation. /78 It is likely that the model employed by W. K. Hartmann for passage of crater-forming bodies through the Venutian atmosphere requires further refinement. The same density curve for distribution of impact craters in the interval of diameters 22 - 64 km on the diagram which does not take into consideration the influence of the atmosphere coincides fairly well with the isochrone of 1 billion years (fig. 3). A conclusion could be drawn from this coincidence that there is no noticeable influence of the Venutian atmosphere on the passage of impacts forming craters over 22 km. It should be noted that preliminary evaluation of the age of the impact crater complex on Venus of 0.5 - 1 billion years was determined using the earlier model of W. K. Hartmann [9] on an area 2/3 of the entire photographic area of the spacecraft Venera -15 and - 16.

The good preservation of the majority of impact structures over 8 km in diameter indicates that from the beginning of the formation of the observed population of impact craters, the depth of reprocessing of the surface layer by geological processes or the thickness of cover deposits within the photographic region did not exceed the first hundred meters. This means that the formation of the noncrater relief of the surface on the scale of the first hundred meters mainly ended apparently 1 billion years ago.

TABLE 1.
DISTRIBUTION OF IMPACT CRATERS BY CLASSES AND AS A WHOLE FOR AREA OF PHOTOGRAPHY FROM SPACE VEHICLES VENERA - 15 AND - 16 (115 million km^2)

Интервалы диаметров кратеров, км (a)	I класс (b)			II класс (b)			III класс (b)			IV класс (b)			Сумма всех классов (c)		
	N	$N/10^6$	σ	N	$N/10^6$	σ	N	$N/10^6$	σ	N	$N/10^6$	σ	N	$N/10^6$	σ
8—11,3	2	0,017	0,012	4	0,035	0,017							6	0,052	0,021
11,3—16	5	0,043	0,019	8	0,070	0,025	5	0,043	0,019				18	0,156	0,037
16—22,6	5	0,043	0,019	21	0,183	0,040	7	0,061	0,023	1	0,009	0,009	34	0,296	0,051
22,6—32	6	0,052	0,021	22	0,191	0,041	7	0,061	0,023	4	0,035	0,017	39	0,339	0,054
32—45,3	5	0,043	0,019	9	0,078	0,026	6	0,052	0,021	3	0,026	0,015	23	0,199	0,042
45,3—64	4	0,035	0,017	3	0,026	0,015	3	0,026	0,015	5	0,043	0,019	15	0,130	0,034
64—90,5				5	0,043	0,019	1	0,009	0,009	2	0,017	0,012	8	0,069	0,025
90,5—128				2	0,017	0,012	1	0,009	0,009				3	0,026	0,015
128—181							1	0,009	0,009				1	0,009	0,009
(d) Сумма	27	0,233		74	0,643		31	0,270		15	0,130		147	1,276	

Key:
a. intervals of crater diameters, km
b. class
c. sum of all classes
d. sum

Note: In tables 1 and 2, the number of craters in a specific interval of diameters is N; $N/10^6$ is the number of craters normed for area 10^6 km^2; σ is evaluation of the standard deviation $\sigma = \sqrt{N}/10^6$.

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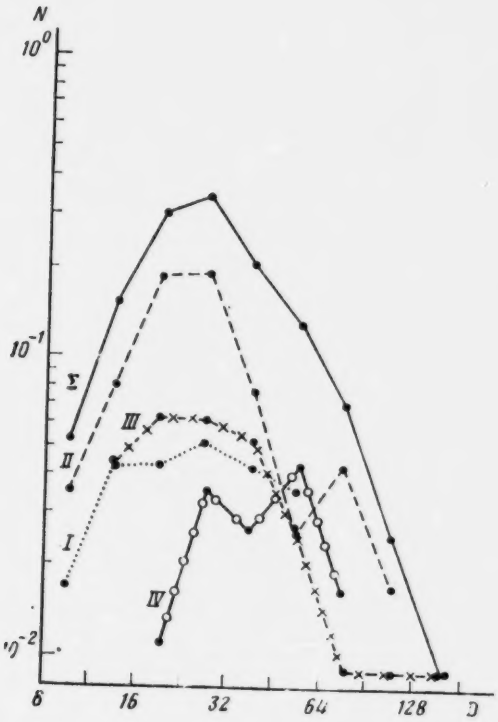

Figure 2. Graphs for Distribution of Number of Impact Craters Identified on Entire Studied Area, Depending on Diameter of These Structures

Key:

Σ. curve for distribution of entire set of impact craters,

I, II, III, IV. distribution curves of impact craters of corresponding classes.

N. number of craters normed for area equal to 10^6 km

D. intervals of diameter dimensions, km

The photographic territory is nonuniform in a geological sense, however. Localities of several types are isolated on it in morphological features of the relief structure: plains, bands of ridges, areas of platform development of very rugged relief ("parquet"), Lakshmi plateau and its surrounding mountainous region, large volcanic - tectonic arch elevations [2, 3]. In all localities except the last, complexes have been established of impact craters for which the corresponding curves of distribution density /79

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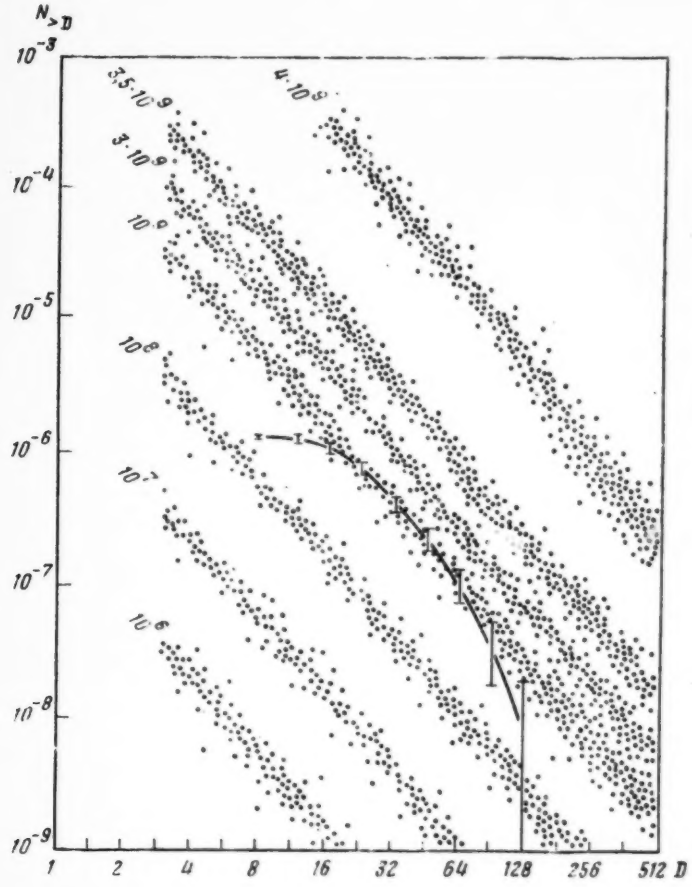

Figure 3. Forecasting Age Cumulative Relationships for Distribution of Density of Impact Craters for Venutian Surface Without Consideration for Influence of Atmosphere on Passage of Crater-forming Bodies through It (from W. K. Hartmann [7, fig. 3]) with Applied Curve of Cumulative Distribution of Impact Crater Density from Photographic Data of Venera - 15 and -16.

Key:

$N_{>D}$. cumulative number of craters with diameter greater than D normed for 1 km^2

D. intervals of diameter dimensions of impact craters, km.

have been constructed (impact craters of the Lakshmi plateau and its surrounding mountain region are viewed as a single complex because of the hypothesis that these localities are geologically

interrelated [6]) (table 2, fig. 4). The obtained curves differ somewhat from each other, indicating the existence of some age differences. But, unfortunately, they overlap within the confidence intervals (σ) of the density values, from which that statistical indistinguishability of the age estimates defined from these curves follows strictly speaking.

However, in terms of a rough estimation, some relative differences between them should nevertheless be discussed. For this purpose, averaged ratios of distribution density of impact craters for each locality to the distribution density of the entire crater population have been computed for structures over 22 km in diameter without consideration for the confidence intervals (right branches of the curves). These relationships for the set of impact craters of the Lakshmi plateau and its surrounding region, bands of ridges, plains and areas of "parquet" are respectively 2.1, 1.9, 1 and 0.9. If we take into consideration the slight change in time in the flow of crater-forming bodies in the last 1 billion years [5, 12], then the quantities obtained in this manner can only be viewed as qualitative indicators of the age differences in the set of impact structures.

It would seem that the set of impact structures on the Lakshmi plateau and its surrounding mountain region should have the greatest relative age in this series. However, the high-altitude levels of the surface here on the average are 3 - 6 km higher than the high - /81
altitude surface levels of the plains and the bands of ridges. This difference in the hypsometric position determines the difference in the mass of the atmospheric column above these localities. In turn, this difference apparently entails the higher density of impact crater distribution and displacement of the maximum of this distribution towards the smaller diameters as compared to similar distributions for localities of other types (fig. 4) observed for the crater complex of the Lakshmi plateau and its surrounding region. A similar displacement was predicted previously by the models for passage of crater-forming bodies through

TABLE 2.
DISTRIBUTION OF IMPACT CRATERS ON DIFFERENT TYPES OF LOCALITY FROM PHOTOGRAPHIC RESULTS OF SPACE VEHICLES VENERA - 15 AND - 16

(a) Интервалы диаметров кратеров, км	Равнины 83,3·10⁶ км² (b)			Пояса гряд (c) 11,2·10⁶ км²			«Паркет» (d) 13,3·10⁶ км²			Плато Лакшми с горным обрамлением 2,9·10⁶ км² (e)		
	N	N/10⁶	σ	N	N/10⁶	σ	N	N/10⁶	σ	N	N/10⁶	σ
8—11,3	4	0,048	0,023							2	0,689	0,486
11,3—16	14	0,168	0,042	2	0,178	0,126				2	0,689	0,486
16—22,6	22	0,264	0,053	4	0,357	0,179	3	0,226	0,130	5	1,724	0,772
22,6—32	26	0,312	0,058	5	0,447	0,200	6	0,451	0,184	2	0,689	0,486
32—45,3	15	0,180	0,044	5	0,446	0,200	2	0,150	0,106	1	0,344	0,344
45,3—64	10	0,120	0,038	3	0,268	0,154	1	0,075	0,075	1	0,344	0,344
64—90,5	6	0,072	0,029	1	0,089	0,089	1	0,075	0,075			
90,5—128	2	0,024	0,016							1	0,344	0,344
128—181	1	0,012	0,011									
(f) Сумма	100	1,200		20	1,785		13	0,977		14	4,827	

Key:

a. intervals of crater diameters, km
b. plains
c. band of ridges
d. "parquet"
e. Lakshmi plateau and surrounding mountain region
f. sum

the Venutian atmosphere [7, 10]. Therefore the observed high density of smaller craters on the Lakshmi plateau and its surrounding mountain region cannot be viewed as proof for their longer accumulation time, but indicates rather the relatively greater number of corresponding crater-forming bodies that reach the surface at these altitudes.

The relative age of formation of the set of crater plains does not coincide randomly with the average age of the entire complex (ratio 1): the plains dominate in area and the number of craters on them significantly exceeds the number of craters on other localities. In this case one should bear in mind that the surface of the plains themselves is nonuniform in morphological characteristics, and different regions of the plains, judging from their geological structure sould be of various ages [1 - 3]. It is impossible to evaluate the temporal correlations between the individual regions of the plains in density of impact craters because

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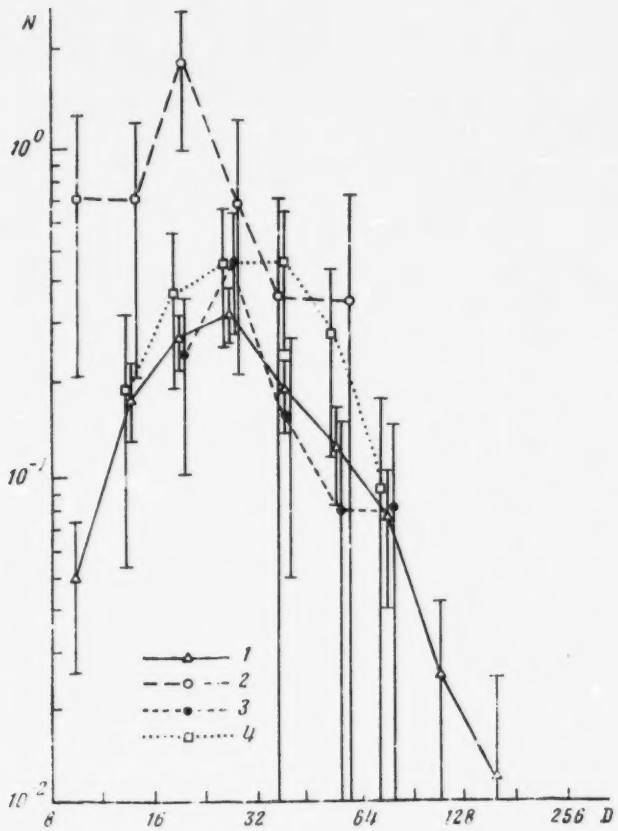

Figure 4. Graphs for Distribution of Number of Impact Craters Depending on Diameter of These Structures on Different Types of Locality

Key:

1. on plains
2. on Lakshmi plateau together with surrounding mountain region
3. on "parquet"
4. on bands of ridges
- N. number of craters, normed on area equal to 10^6 km^2
- D. intervals of crater diameter dimensions, km

the geological boundaries between them are currently obscure; they are currently being pinpointed.

For crater complexes of "parquet" and plains, judging from the quantities cited above for the relationships (0.9 and 1

respectively), no significant age differences are found. It is only impossible to exclude a somewhat longer formation time apparently for complexes of craters on ridge bands.

Of course it is difficult to speak with confidence about the poesible sequence of completion in the formation of the noncrater relief from this comparison of the distribution density of impact structures on different localities. However, one can hypothesize with a certain percentage of probability that the noncrater relief of plains, areas of development of "parquet," apparently the Lakshmi plateau and its surrounding mountain region completed formation approximately at the same time, 1 billion years ago. The relief of the ridge band was formed close, but apparently somewhat earlier than this time. The youngest noncrater relief of the surface could be on the volcanic - tectonic elevations (Bell, Metida and partially the areas Beta and Ulfrun covered by photography) where no impact structures have been found. One should bear in mind, however, tht that if the average density of propagation of impact craters here is the same as on the entire photographed territory, then on the area of these elevations (4.5×10^6 km) one could expect to find only five craters. Therefore, the lack of impact structures on them could be related to the probability fluctuation in their distribution.

Interesting features in the correlation of morphologically recent craters (I and II classes) and old craters (III and IV classes) are revealed on the histograms constructed both for the entire complex of these structures and for the complex of individual localities (fig. 5). The histograms show considerable dominance of the recent craters on all types of locality, except the areas of development of the "parquet" where the opposite picture is observed; there are considerably more old craters here than recent ones. These correlations with regard for the comparatively close time for formation of the observed crater complexes on different localities suggest that the intensity of destruction of craters in the areas of development of the "parquet" possibly was higher than in other localities. Based on this one can

explain another observation, a shortage of craters less than 22 km in diameter on the "parquet" as compared to the Lakshmi plateau and its surrounding mountain region (fig. 4). The slight difference in the hypsometry of the surface of these localities hardly has a significant influence on the densities of the crater complexes. However, the shortage of small craters on the "parquet" could also be a consequence of the strong ruggedness of the "parquet" relief, and the nature of this ruggedness is such that the structural elements of the craters could be lost in the structural elements of the "parquet." /82

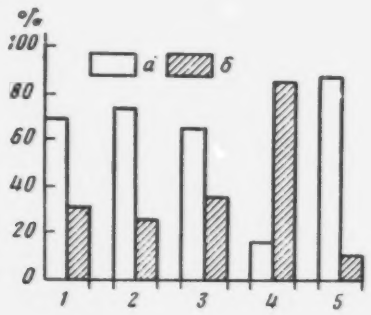

Figure 5. Histograms for Distribution of Morphologically Recent Impact Craters of I and II Classes (a) and Morphologically Old Impact Craters of III and IV Classes (b) for:

Key:
1. entire surface area encompassed by photography (number of craters 147)
2. plains (100)
3. bands of ridges (20)
4. "parquet" (13)
5. Lakshmi plateau and its surrounding mountain region (14)

Conclusions

1. On the territory photographed by the space vehicles Venera-15 and -16 and comprising ¼ of all the planetary surface, the average age of the observed complex of impact craters is estimated at approximately 1 billion years. A characteristic

feature of this complex is the dominance in it of morphologically recent impact craters over older.

2. Comparison of the distribution densities of crater complexes for localities of varying type demonstrates that th noncrater relief of the surface of plains, areas of propagation of "parquet," the Lakshmi plateau and its surrounding mountain region, in all likelihood, completed its formation approximately by one moment in time, about 1 billion years ago. Apparently, formation of the relief of ridge bands was completed somewhat earlier than this, the format of the relief of volcanic - tectonic regions of Beta, Bell, Ulfrun and Metida continued most likely later than 1 billion years.

3. In areas of "parquet" development, the intensity of destruction of the impact structures in the last billion years was apparently higher than in any other examined locality.

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